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HOLE DRILLING BREAKTHROUGH IN BE SHELLS

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Subject: Hole Drilling Breakthrough in Be Shells

This is a brief memo look at the problem of determining whether one has broken through the inside plastic mandrel of a sputtered Be shell. This is important because the next step is the thermal removal of the mandrel, and failure to break through the plastic, even if through the Be, makes our process[1] at best difficult.

Described below are two possible approaches, the first somewhat high tech and maybe not possible, the second definitely low tech but certainly doable.

High Tech Approach

This approach is based on the relatively slow loss of internal capsule pressure through a sufficiently narrow fill hole. Imagine a pressure vessel of small volume V_v or better for simplicity let V_v be the volume of the vessel *less* the volume that a shell would occupy in the vessel. Let the internal volume of the shell be V_{sh}. Suppose we pressurize the vessel containing a shell to a modest pressure so that the pressure inside the shell (assuming that the hole went through) at time $t = 0$ is $P_{sh}(0)$. Now suppose one instantaneously (more about this later) reduced the pressure in the vessel to zero (or some small value) and then sealed the system and monitored the pressure in the vessel as a function of time. Thus, assuming instantaneousness, the pressure in the vessel at $t = 0$ would be $P_v(0) = 0$. What happens next? Well, if there is a small hole through the capsule the gas inside the capsule will stream out, but because the hole is small this will take time, and what one would see is a relatively slow increase in the pressure in the vessel. The question we wish to answer is "How slow?" and whether the rate of pressure rise is at all consistent with experimental realities (*i.e.* "instantaneousness"). Of course if the hole were NOT all the way through the capsule then there would be no rise in pressure. But the reality is that vacuum systems leak (or degas) and there is always a pressure increase. The purpose of this calculation is to try to determine whether we have any experimental space to work in.

I solved in detail the problem of gas flow through a small pipe in a previous memo[2] and will start from some of the results there. I showed that (eq 11 of that memo)

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[1] Bob Cook, Steve Letts, and Steve Buckley, "Experimental confirmation of CH mandrel removal from Be shells," LLNL memo, June 8, 2004. A copy can be obtained from Bob Cook.
[2] Bob Cook, " Mandrel Burn-Out in Be Shells - Gas Flows," LLNL memo, March 9, 2004. A copy can be obtained from Bob Cook.

$$\frac{dP_{\mathrm{sh}}}{dt} = \frac{A \cdot P_{\mathrm{v}}}{V_{\mathrm{sh}}} \cdot P_{\mathrm{sh}} - \frac{A}{V_{\mathrm{sh}}} \cdot {P_{\mathrm{sh}}}^2 \tag{1}$$

where

$$A = \frac{\pi a^4}{8\eta w} \tag{2}$$

and a is the hole radius, η is the gas viscosity, and w is the hole length. In the previous case P_{v} was taken as being constant, but in this case it can be related to the internal pressure of the shell at time t by

$$\left(P_{\mathrm{sh}}(0) - P_{\mathrm{sh}}(t)\right) \cdot V_{\mathrm{sh}} = P_{\mathrm{v}}(t) \cdot V_{\mathrm{v}} \tag{3}$$

where we have assumed for simplicity that $P_{\mathrm{v}}(0) = 0$. Given this eq 1 can be rewritten as

$$\frac{dP_{\mathrm{sh}}(t)}{dt} = \frac{A \cdot P_{\mathrm{sh}}(0)}{V_{\mathrm{v}}} \cdot P_{\mathrm{sh}}(t) - \left(\frac{A}{V_{\mathrm{v}}} + \frac{A}{V_{\mathrm{sh}}}\right) \cdot P_{\mathrm{sh}}(t)^2 \tag{4}$$

or letting

$$P_{\mathrm{sh}}(t) = 1 / z(t); \quad C_1 = \frac{A \cdot P_{\mathrm{sh}}(0)}{V_{\mathrm{v}}}; \quad C_3 = \left(\frac{A}{V_{\mathrm{v}}} + \frac{A}{V_{\mathrm{sh}}}\right) \tag{5}$$

we have

$$-\frac{1}{z^2} \cdot \frac{dz}{dt} = C_1 \cdot \frac{1}{z} - C_3 \cdot \frac{1}{z^2} \quad \text{or} \quad \frac{dz}{dt} + C_1 \cdot \mathrm{z} = C_3 \;. \tag{6}$$

The solution to this is

$$z(t) = \frac{C_3}{C_1} + \mathrm{const} \cdot e^{-C_1 t} = \frac{C_3}{C_1} + \left(z(0) - \frac{C_3}{C_1}\right) \cdot e^{-C_1 t} \tag{7}$$

or

$$P_{\mathrm{sh}}(t) = P_{\mathrm{sh}}(0) \cdot \frac{V_{\mathrm{sh}}}{V_{\mathrm{sh}} + V_{\mathrm{v}}\left(1 - e^{-\frac{A \cdot P_{\mathrm{sh}}(0)}{V_{\mathrm{v}}} \cdot t}\right)}. \tag{8}$$

Since we intend to monitor the vessel chamber eq 3 can be used to express this pressure as

$$P_{\mathrm{v}}(t) = \frac{P_{\mathrm{sh}}(0)\cdot V_{\mathrm{sh}}}{V_{\mathrm{v}}} \cdot \left(\frac{V_{\mathrm{v}}\left(1 - e^{-\frac{A\cdot P_{\mathrm{sh}}(0)}{V_{\mathrm{v}}}\cdot t}\right)}{V_{\mathrm{sh}} + V_{\mathrm{v}}\left(1 - e^{-\frac{A\cdot P_{\mathrm{sh}}(0)}{V_{\mathrm{v}}}\cdot t}\right)} \right). \tag{9}$$

This looks complicated, but quickly it checks at $t = 0$ and $t = \infty$ give values of 0 and $P_{\mathrm{sh}}(0)\cdot V_{\mathrm{sh}} \,/\, (V_{\mathrm{sh}} + V_{\mathrm{v}})$ which are correct.

What are reasonable parameters? We will take the initial pressure in the shell, $P_{\mathrm{sh}}(0)$, as 10 atm in the examples that follow. For the volume of the shell we will use a 1 mm radius, thus the volume is about 0.0042 cm^3. For the volume of the vessel we'll look at 1000 times the volume of the shell, which 4.2 cm^3. The pressure measured at long *t* scale inversely with vessel size, and thus determine the magnitude of the pressure measured, but does not affect the time constant. However experimental issues (how rapidly the volume can be evacuated, how accurately the pressure can be measured, leakage, etc) may be impacted by this volume. Clearly the time constant is controlled by *A*, but our ability to measure it may depend on these other parameters. For *A* (eq 2) the gas viscosity, η, and tube length, *w*, we will take as 18.6 µPa-s (the value[3] for air at 300 K) and 150 µm respectively. For the tube diameter (2*a*) we will look at 1, 2, 3, 5, and 10 µm. It is not entirely clear what is appropriate since the holes are not uniform, but this range will give us a flavor of the variation.

Shown in Figure 1 (next page) is the pressure rise in the vessel as a function of time for the various hole diameters. We perhaps see the limits of this experimental technique. If the hole is too large, perhaps greater the 5 µm, then the leakage through the hole will probably keep up with the attempt to initially evacuate the vessel, and as a result it will appear that we did *not* drill through. On the other hand, if the hole is very small, perhaps 1 µm, the pressure rise due to gas leaving the shell might be slow enough to be comparable to the leak rate of the vessel. In this case making the vessel smaller helps significantly, since the leak rate of the vessel might be reduced and more importantly the rate of increase in pressure in the vessel due to the flow out of the capsule would be increased. For this reason it makes sense to make as small a pressure vessel as possible.

One advantage of this type of measurement opposed to the low tech method that follows is that in principle at least the measurement gives information about the *size* of the hole, not just whether we have broken through or not. This information will

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[3] Handbook of Chemistry and Physics, 78th ed, p. 6-194. One could increase this somewhat by using a different gas (*e.g.* Ne has a value of 32.1 µPa-s, the highest in the table).

certainly be useful during the optimization of laser drilling, but also might be a routine quality control check as we go into production.

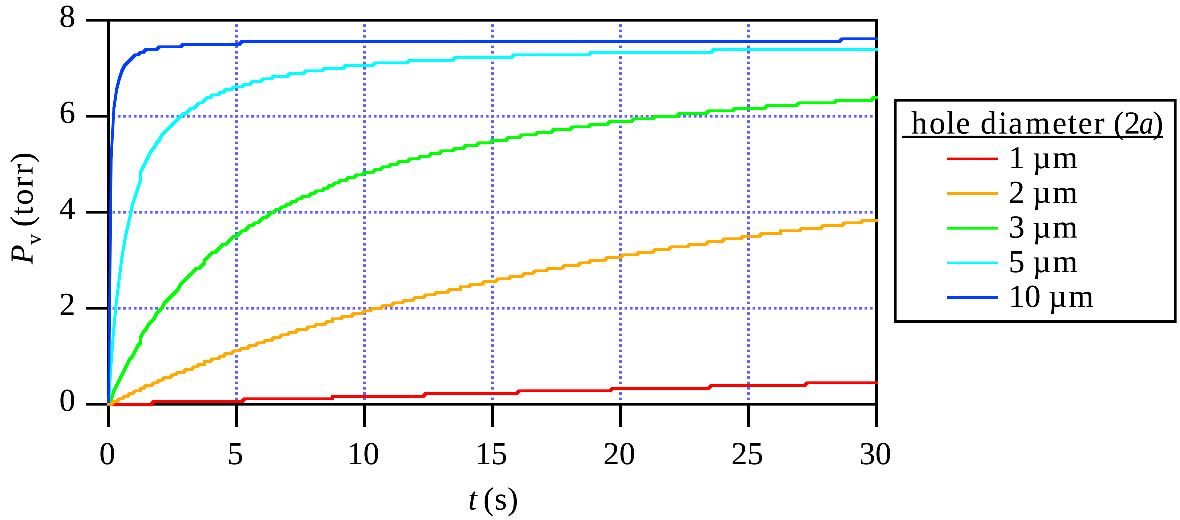

Figure 1. Pressure rise in the vessel as a function of time for different hole diameters.

Low Tech Approach

If we simply want to know whether we drilled all the way through then there exists a simple test. If we weigh the drilled shell, then attempt to fill it with water by submerging it, evacuating (or at least down to 25 torr or so) the system to remove the air from the shell, then bring the external pressure back up to 1 atm to force water into the shell, we can tell if we were successful (*i.e.* we drilled all the way through) by reweighing the water-filled shell. The weight of a 2 mm diameter 150 µm wall Be shell with a 15 µm wall mandrel inside is about 4.23 mg, if we fill it with water the mass is about 8.42 mg, clearly a measurable difference. The water can be easily removed by heating the shell to say 150 °C for a few minutes as part of the thermal removal of the mandrel. Clearly if the shell doesn't gain weight then either the drilling is not through or the hole at its narrowest point is such that capillary forces are greater than the roughly 1 atm driving pressure. If this is the case then the hole is probably too small anyway.

This method of introducing water into drilled capsules has previously been used with thin walled (~20 µm) capsules to pressure test them for strength, so we know that it works at least for those holes. Since it is easy to do we should adopt this method immediately while the somewhat more sophisticated "High Tech" approach is evaluated.

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